Acquisition of UHF and X-Band ISAR imagery using 1/35th Scale-models

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ABSTRACT

Radar detection and identification of ground targets in diverse environments is a subject of continuing interest. It has long been known that different radar bands have advantages for different environmental conditions. For example, it has been shown that detection of targets under foliage is more easily accomplished using longer wavelength radars since there is less attenuation at these frequencies. However, higher frequency radars offer greater resolution that is crucial in target identification. Because each radar band has its own unique strengths and weakness, one current approach is the use of dual-band radar platforms. With two radar bands working simultaneously, the strengths of each radar band can be used to compliment the other. ERADS has constructed two full polarimetric compact radar ranges to acquire X-Band and UHF ISAR imagery data using 1/35th scale models. The new compact ranges allow data to be taken that can simulate a multi-frequency radar platform with frequencies low enough to detect obscured targets and high enough to provide useful resolution to aid in target identification once they have been detected. Since both compact ranges use the same scale factor, this allows measurement of the same target at the two spectral regions simply by moving the target model from one compact range to the other. Data can thus be taken whose differences in scattering are due only to the difference in radar frequency, eliminating variations due to differences in target models as well as the surrounding ground clutter. Detailed descriptions of the new compact ranges will be presented along with results from sample data sets.

Keywords: Sub-millimeter wavelength, Radar, Imagery, Modeling, UHF, X-band.

1. INTRODUCTION

Since the first measurements at sub-millimeter wavelengths were made on scale models in the late 1970's[1] the U. S. Army National Ground Intelligence Center (NGIC) has funded the development of state-of-the-art compact radar ranges to obtain high-resolution target signature data on scale models of tactical targets. These data have become essential for successful development of enhanced capabilities such as assisted target recognition (ATR). For this reason NGIC developed the Expert Radar Signature Solutions (ERADS) program, which includes NGIC (Rivana Station), NGIC (Aberdeen Proving Ground), the Submillimeter-Wave Technology Laboratory (STL) at University Massachusetts Lowell, University of Virginia Semiconductor Device Lab, Georgia Tech. Research Institute, and Tufts University. As part of its multi-method signatures approach, the ERADS Program develops compact radar ranges to collect radar signatures and also develops high-fidelity scale models of targets of interest. Over the past 20 years compact ranges have been developed to model VHF/UHF, X-band, Ka-band, and W-band radar systems. Other radar band measurements are possible, since target signature data are collected by measuring scale models at proportionally scaled wavelengths. Since VHF/UHF is a frequency of interest for detecting targets, and X-band (10GHz) is a radar frequency that is of particular interest in identifying targets, we have developed new compact ranges to simulate radar systems operating in these radar bands.

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The mathematics and theory of using scale models and proportionally scaled wavelengths to study the scattering of electromagnetic radiation has been well known since the late 1940's. Recent studies have shown that radar scattering data taken on a high fidelity 1/16th scale model compares very well with the same data taken on the full-scale target.[2] Heretofore the compact radar ranges developed under the ERADS program have performed the vast majority of measurements using 1/16th scale models. With the recent development of a 6-18GHz compact range to model VHF/UHF[3] at 1/35th, scale and the newly completed 350GHz compact range to model X-band at 1/35th scale, it has become convenient to make use of the wide variety of 1/35th scale commercially available models. These models make a useful supplement to the high-fidelity 1/16th scale models, which are normally built using all in-house resources. Commercially available models cannot in general be used without modifications that will ensure that they accurately reflect the details of the real target. An expert model builder with detailed knowledge of the actual target is needed to meticulously apply these modifications.

There is a growing interest in detecting and identifying targets under trees or targets that are partially obscured. It is known that detection of targets under foliage is more easily accomplished using longer wavelength radars, since there is less attenuation at UHF frequencies. However, higher frequency radars offer the greater resolution that is crucial in target identification. Since ground targets are commonly *detected* at lower frequencies and *identified* by higher frequency radars the use of the new 1/35th scale compact ranges will allow measurements that simulate a multi-frequency radar platform. Since both compact ranges use the same scale factor, measurements can be made of the same target at the two spectral regions simply by moving the target model from one compact range to the other. To ensure the correct modeling of the target scene, great care is given to matching the dielectric properties of the ground terrain on which the target is to be measured. Typically, a moldable plastic is loaded with a dielectric material to produce the desired reflectivity from the surface of the ground plane. The plastic is poured into a mold designed to simulate the desired roughness (such as desert, field soil etc.). A separate ground plane made from the same mold but with different dielectric loading is made for use in each compact range to ensure reflectivity of the ground is simulated properly at different frequencies. Data can thus be taken whose differences in scattering are due only to the difference in radar frequency. Variations due to differences in target models and the surrounding ground clutter are eliminated, since it is the same model and the ground planes are constructed from the same mold.

2. THE 350GHz COMPACT RADAR RANGE

The 350GHz compact radar range designed to model X-band radar has been described previously[4] and will be only briefly described here. In Ref (4) the results of a preliminary series of diagnostic tests and sample imagery had been presented. In the current work, sample ISAR imagery has been taken on 1/35th scale targets and comparisons made with previous data sets taken at other scale factors. The 350GHz compact range is shown in a simplified view in Figure 1. In order to model X-band using a 1/35th scale model, two very-high-stability far-infrared (FIR) lasers were developed as the base transmit and receive sources. The lasers consist of two ultra-stable, 150W, grating-tunable CO_2 lasers that are used as the optical pumps for the two FIR lasers. The CO_2 lasers are set to produce 10μm wavelength radiation (10R14 and 10R32 laser transitions, respectively). The outputs of the lasers are used to excite the molecular gas transitions in deuterated Formic acid (HCOOD). The formic acid FIR lasers then produce frequencies of 323.6770GHz and 325.8842GHz, respectively. One laser is used as the local oscillator for the receiver diodes. The receiver diodes shown in Figure 1 consist of a new, high-efficiency, ultra-wide-bandwidth diode mounted in a fundamental waveguide.[a] A high gain diagonal horn that produces a very good beam pattern is used as a transition from waveguide to free space. The local oscillator (LO) laser beam is propagated quasi-optically to illuminate the receiver diode.

The field-of-view of the receiver diode is set by a combination of focusing mirrors and lenses such that it will achieve an overlap with the transmitter. The transmitter diodes shown in Figure 1 consist of diodes that are very similar in mechanical design to the receiver diodes. Identical high-gain diagonal horns are also used to form the transition from fundamental waveguide to free space for the transmitter diodes. The output of the transmitter laser is propagated to the transmitter diodes and illuminates them through a specially designed silicon etalon mixer optic. The transmitter diodes then mix the incident laser power with an externally applied variable frequency signal from a 2-50GHz microwave sweeper. The transmitter diodes are optimized to efficiently radiate the resulting sideband power. The silicon etalons, which are designed for 99% transmission of the laser frequency, reflect the sideband frequency with very high

[a] Diode type VDI-WR2.8-FM-S00012 From Virginia Diodes Inc. 321 West Main Street Charlottesville, VA 22903.

efficiency. This technique allows the frequency-tunable sideband to be separated from the un-shifted laser frequency. The upper and lower sidebands are then filtered out from one another by the use of a high efficiency drilled hole filter, consisting of an aluminum plate with a hexagonal pattern of precisely drilled holes. Passing the sideband radiation through this filter efficiently separates the sidebands so that only one is transmitted to the target. The transmitter sideband is then collimated using a 45-inch diameter 250-inch focal length mirror that is used as the primary antenna for illuminating the target. Backscattered electromagnetic radiation is collected by the primary antenna and propagated into the receiver.

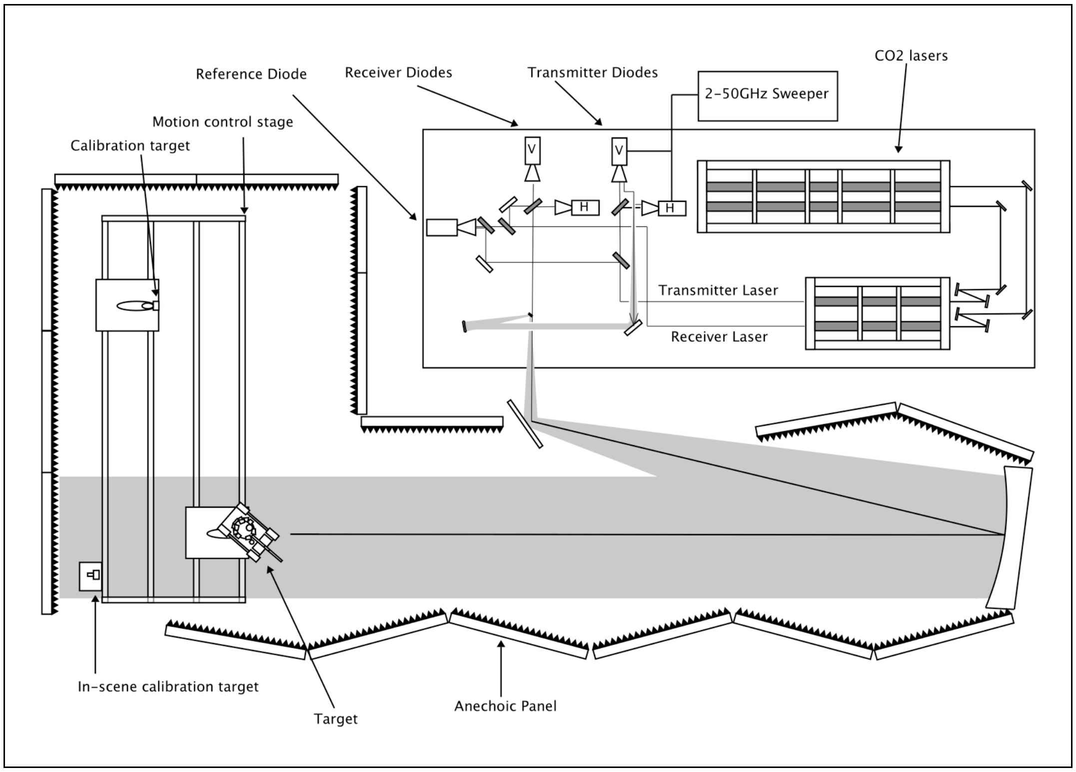

Figure 1. Diagram of the 350GHz compact radar range.

350GHz Compact Range	**(X-Band Full Scale)**
350 GHz Center Frequency	(10 GHz Full scale)
35 GHz Bandwidth	(1 GHz Full Scale)
0.169” Range Resolution	(5.92” Full Scale)
20” Two Way Beam Width (-3dB)	(58.3’ Full Scale)
Far Field Beam, 0.3˚ bistatic	
Fully Polarimetric HH, HV, VH, VV amplitude and phase	

Table 1. Radar parameters for the 350GHz compact range when modeling X-Band.

The target shown in Figure 1 can be mounted either on a low cross-section pylon to provide free space data collection, or on a dielectric ground plane to simulate various environments such as desert, wet or dry soil, asphalt, etc. The pylon is set in an anechoic chamber whose walls are covered with a specially designed material (FIRAM®) that is highly absorbing at 350GHz. This setup is done to minimize the amount of backscattered radiation from objects other than the target. The tunable microwave source is swept in order to produce a frequency chirp centered at 350GHz with a

35 GHz bandwidth, accurately modeling 10GHz with a bandwidth of 1GHz. While this bandwidth provides a range resolution of 0.169 inch at 350GHz, it corresponds to a range resolution of 5.92 inch on the (full-scale) X-band target. Although the filters are optimized for the upper sideband to simulate X-band at 350GHz, the lower sideband could in principle be used in order to produce a tunable frequency centered at 300GHz with 35GHz of bandwidth. Either sideband could be used, depending on the requirements of the measurement. The compact range is designed to transmit and receive both horizontal and vertical polarization, providing the full polarimetric scattering matrix information. The general operating parameters of the compact range are listed in Table 1. By using techniques similar to those described in Ref(5) and Ref(4) data can be collected to provide 2-dimensional and 3-dimensional imagery.

3. 350GHz RESULTS

3.1. Comparison of 1/35th scale with 1/16th scale T72 data.

The results of diagnostic measurements of the 350GHz compact range have been presented previously[4]. The two-way field of view of the compact range was determined along with the phase variation of the wave front across the radar beam in the region where the target would be scanned. The two-way half-power diameter of the compact range was measured to be 20" corresponding to a 1/35th scale distance of 58.' Measurements of a small flat plate showed that the measured RCS of a flat plate scanned through 360˚ of azimuth angle matched to a very high degree the theoretical RCS generated using equations from the Geometric Theory of Diffraction (GTD). The power of the transmitter was also measured across the 35GHz of bandwidth and found to have an average of ½mW. Sample imagery in azimuth and elevation cross-range were generated at a single frequency on several different 1/35th scale models as a demonstration of the imaging capabilities of the compact range, however no frequency swept ISAR imagery was available at that time.

As a test of the performance of the 350 GHz compact range it is important to measure not only known simple objects but also to measure complex targets whose signals will tend to stress the upper and lower limits of the entire radar system. In this section we present the results of sample ISAR imagery and RCS taken on a 1/35th scale T72 tank compared with the corresponding imagery and RCS of data sets taken on 1/16th scale models and full scale turntable measurements of a T72 tank. Figure 2 shows the results of a comparison of the three data sets in which the ISAR images were formed at identical angles. The data in Figure 2 show the results for a T72 tank at 10˚ elevation. In all data sets the procedure for measurements were identical. The radar system is first calibrated using known test objects. Once calibration is completed the target is placed into the target zone of the radar system on a turntable or rotation pylon that will vary the azimuth of the target. The radar system performs a linear frequency chirp on the transmitter and detects the back-scattered radiation from the target. Complex data pairs of in-phase and quadrature signals are stored on the computer for later analysis.

The images generated in Figure 2 are produced by the application of a Fourier transform across the frequency chirp to determine down-range followed by a Fourier transform across the appropriate angular increment to generate azimuth cross-range. The resulting pixel sizes are 5.9" x 5.9" square in full-scale units. For simplicity only the Vertical-transmit and Vertical-receive (VV) channels are displayed. The azimuth angles shown in Figure 2 are 57˚, 72˚, and 335˚respectively. The images from left to right represent the full-scale target measured using an outdoor turntable facility, the 1/16th scale target measured using a 160GHz compact range, and the 1/35th scale target measured using the 350GHz compact range. It is useful to note that there were some small configuration differences between the three targets in this particular test. The full-scale data were collected using an outdoor facility with a near field phase-front illumination of the target. The scale-model ranges were configured for far-field measurements.

A numerical cross correlation study of the three data sets is currently being performed. The two scale model targets that were used in this study are shown in Figure 3. The pre-existing 1/16th scale T72 model was used as a design template for the modification of a commercially available 1/35th scale model. The 1/35th scale model was built and modified to provide as close a match as possible to the features of the 1/16th scale model. It was necessary to measure the 1/35th scale model in free space since at the time of the measurement a ground terrain of the necessary dielectric constant was still being prepared. The previously generated 1/16th scale model data set was measured on a ground plane designed to simulate the correct reflectivity at X-band using a 160GHz compact. However, the changes in return due to the configuration difference between a target measured in free-space and the same target measured on a ground terrain were completely consistent with results seen in previous studies.[2,6] Identical effects have been observed in this study when correlating the far-field and near-field data sets. Figure 4 shows the RCS of the VV polarization for the 1/35th scale and 1/16th scale T72. The two models measured at different scale factors show the expected agreement with differences accountable to the variation between ground-plane and free-space measurements.

As another useful example, a 1/16th scale M48 tank was measured in the 350GHz compact range. Figure 5 shows a typical ISAR image along with the photo of the scale model at the same angle. Using a 1/16th scale model at 350GHz provides a data set that simulates 21.8GHz or K band. Using the 300GHz sideband instead, it would have corresponded to a scaled frequency of 18.7GHz or Ku band radar. For the 1/16th scale-model the pixel sizes are 2.69" at full-scale. By using different scale factors a variety of frequencies can be simulated using either the 350GHz sideband or the 300GHz sideband.

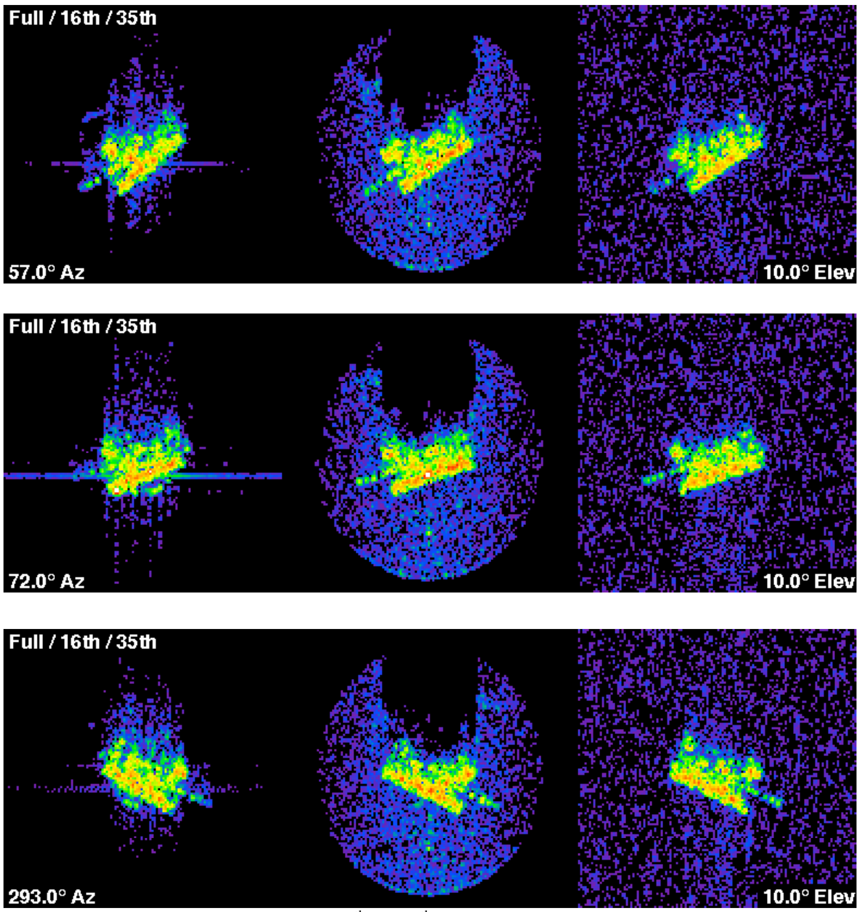

Figure 2. VV ISAR images of the T72 at full-scale, 1/16th, 1/35th scale (from left to right) at azimuth angles of 57°, 72°, and 335°.

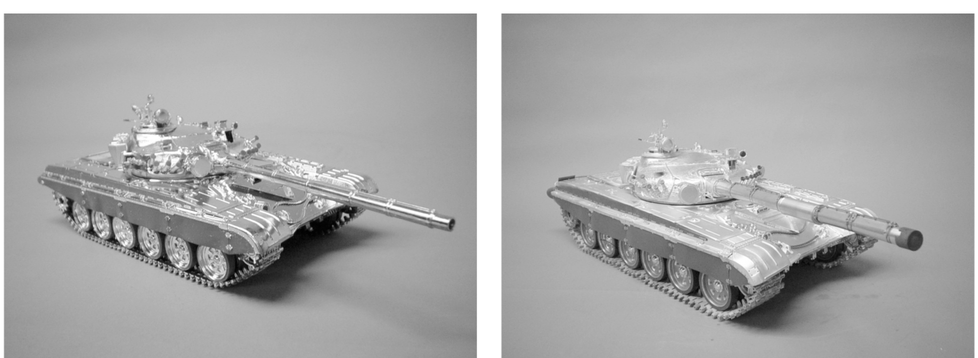

Figure 3. Photographs of 1/35th scale model (left) and 1/16th scale model (right) of a T72 tank used in this study.

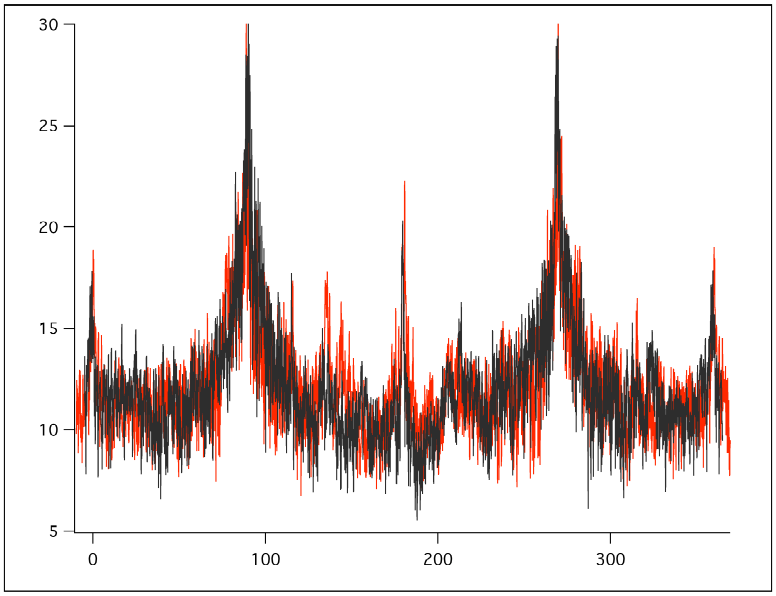

Figure 4. X-band (10GHz) VV RCS return from the 1/16th scale T72 tank model (black line) and the 1/35th scale T72 tank model (Red line).

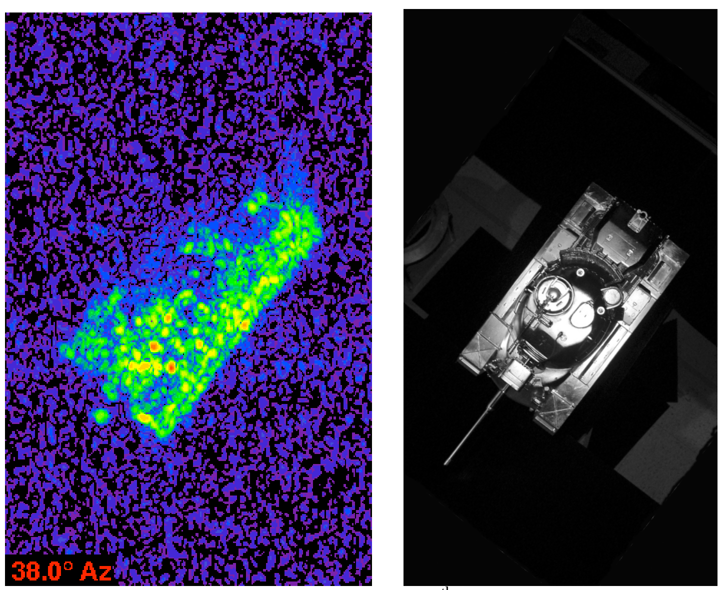

Figure 5. Sample K band (21.8GHz) VV ISAR image of a 1/16th scale model M48 Tank measured at 350GHz.

4. The VHF/UHF Compact Range

A compact range for modeling VHF/UHF frequencies has been described previously in an earlier work[3]. In Ref (3) the compact range consisted of a transceiver based on an Agilent microwave vector network analyzer including an 8341B microwave source, 8511A frequency converter, and an 8510C network analyzer. The frequency bandwidth of the system in Ref (3) was 6GHz with a center frequency of 9GHz. A high-gain horn/lens was used as the primary antenna for this system resulting in an approximate 5” beam diameter at the output of the lens. This Gaussian beam was allowed to expand as it was propagated to illuminate the target. Although this horn/lens combination was effective, it limited the size of the target that could be measured and also produced significant reflections from the lens. The reflections limited the dynamic range of the system. Due to the limitations of the transceiver, special electronics were needed to eliminate unwanted signals that would have interfered with the collection of the radar return from the target. In this paper a newly designed compact range that addresses the limitations of beam diameter and bandwidth of the compact range used in Ref (3) is described.

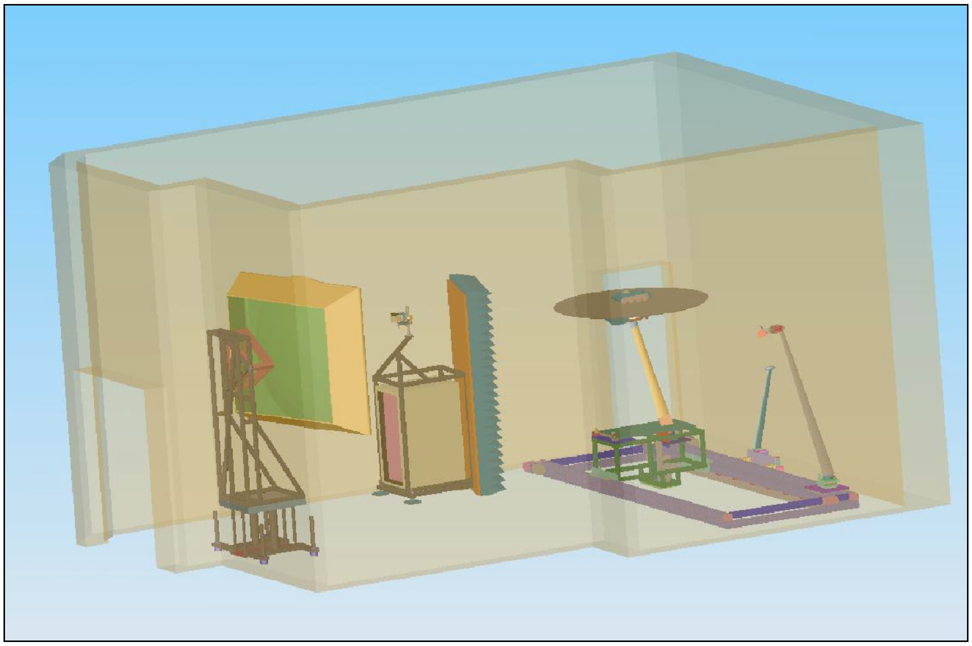

Figure 6. Newly designed VHF/UHF compact range.

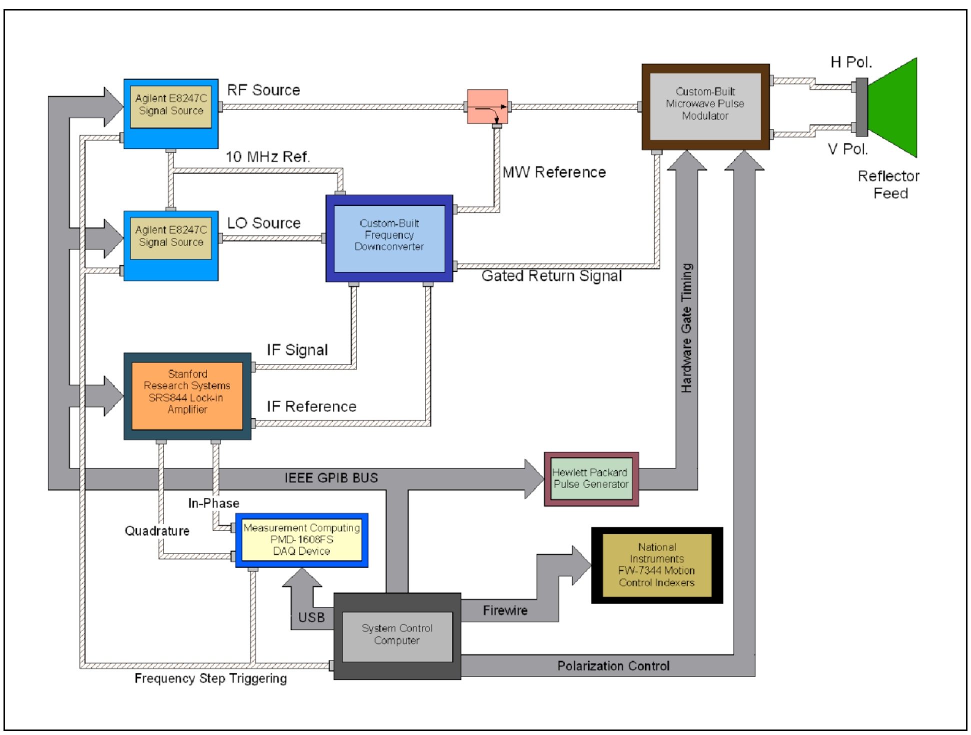

Figure 7. Schematic diagram of the new VHF/UHF compact range.

Figure 6 shows the layout of the improved VHF/UHF compact range. As can be seen in Figure 6, the new compact range replaces the horn/lens combination with a high-quality 7'x6' offset parabolic reflector. This new antenna not only relieves the constraint the horn/lens put on the size of the beam, but also removed the significant reflected signal from the front surface of the lens. New electronics for the transceiver were designed and constructed. The new transceiver can be seen in schematic view in Figure 7. The new sources for the transmitter and local oscillator (LO) consist of two Agilent E8247C signal generators. One signal generator is used as the transmitter and propagated from a feed horn to the parabolic antenna and thus to the target. The second signal generator is used as an LO to down-convert the transmitter, the two signal generators are swept with a fixed difference frequency between them and the signal is detected through a lock-in amplifier whose reference is set to the difference frequency. The Agilent sweepers have a frequency range from 2GHz to 18GHz. Preliminary testing of the transceiver electronics using 1mW of transmit power and a 1ms receiver time constant yielded a received signal with 140dB of signal-to-noise, indicating near optimal transceiver performance. A new anechoic chamber was constructed for the 2-18GHz frequency range with special radar absorbing material covering the inside walls of the chamber. Target mounts and motion control electronics are similar to those used in the 350GHz compact range. This compact range is currently being completed with the transceiver electronics now being installed in the anechoic chamber.

6-18GHz Compact Range	**(VHF/UHF)**
12 GHz Center Frequency	(342 MHz Full scale)
12 GHz Bandwidth	(342 MHz Full Scale)
0.493" Range Resolution	(17.2" Full Scale)
2'x3' Two Way Beam Width (-3dB)	(70'x105' Full Scale)
Far Field Beam, monostatic	
Fully Polarimetric HH, HV, VH, VV amplitude and phase	

Table 2. Radar parameters for the VHF/UHF compact range using a 1/35th scale factor.

Diagnostic measurements are being performed in the new compact range. The output of the transmitter is propagated to the parabolic mirror and collimated before illuminating the target. The backscattered radiation is collected in the receiver and down-converted and digitized. Table 2 shows the operating parameters for the VHF/UHF compact range. The two-way half power beam diameter is 2' x 3' which will allow a target or scene of 105' full-scale size to be measured. The bandwidth of the system is limited by the feed horn optics and is currently being designed for 12GHz. Using a 1/35th scale model, the modeled bandwidth is therefore 342MHz with a resulting down-range resolution of 0.493" (17.2" at full-scale). Since the modeled center frequency is 342MHz and the bandwidth is also 342MHz the modeled frequency spans the VHF and UHF frequency bands. Other scale factors can be used which will model other radar frequencies. For example, if a 1/16th scale model is used the compact range will model a radar system of 750MHz with a down-range resolution of 7.8". The compact range is designed to produce a far-field radar beam using a monostatic transceiver.

Figure 8 shows sample VV ISAR imagery from the 350GHz X-band compact range and the previously measured VHF/UHF data set from Ref(3). The T72 tank target was measured at an elevation angle of 30˚ with the target mounted on a simulated ground terrain. The data sets were collected through 360˚ of azimuth. Several typical angles are shown from 27˚ to 90˚. The X-band ISAR images were formed by integrating across an angular extent to produce 6"x6" pixels. The VHF/UHF images were formed in a similar manner to that described in Ref(3) in which a polar reformatting of the data was performed to allow very wide angle integration to be performed. The resulting images have approximately 3'x3' pixels. Although construction of the new VHF/UHF compact range is nearing completion, it was not possible at the time of this paper to collect ISAR imagery data with it. However, the capabilities of the new compact range will be significantly improved over the system described in Ref(3).

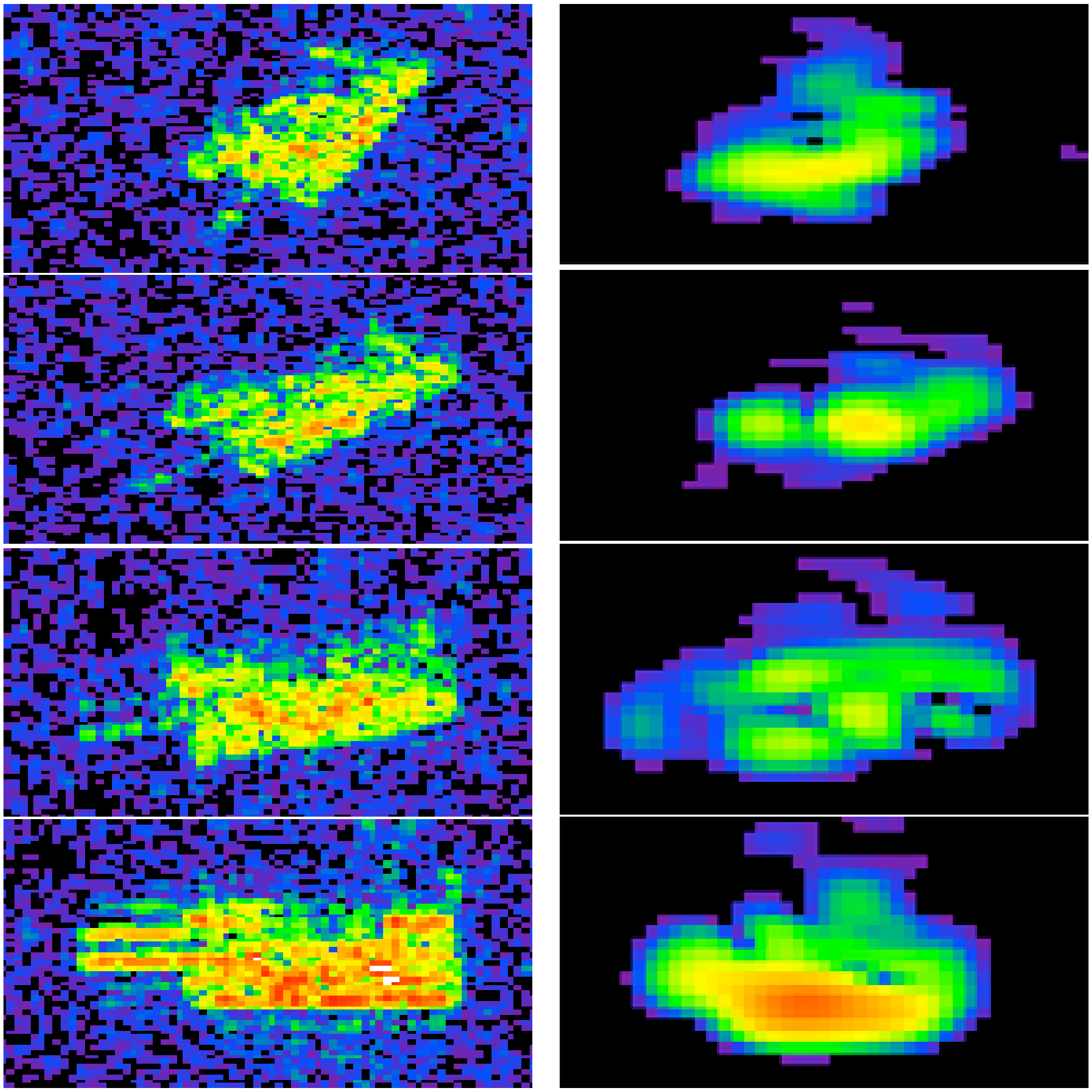

Figure 8. Sample VV ISAR imagery of the T72 tank measured on a ground plane at 30˚ elevation. The X-band imagery appears on the left side of the figure, VHF/UHF imagery appears on the right side. Azimuth angles of 27˚, 49˚, 77˚, and 90˚ are shown from top to bottom.

The VHF/UHF images shown in Figure 8 were taken using a 6GHz bandwidth that corresponds to 0.1714GHz at full-scale. The X-band images shown in Figure 8 were taken with 35GHz bandwidth in the 350GHz compact range giving a corresponding bandwidth of 1GHz at full-scale. The X-band and VHF/UHF images show the expected difference in resolution at the respective center frequencies. It is in general easier to detect obscured or partially obscured targets using VHF/UHF since the targets tend to persist through much larger angular extent. However, the greater resolution at X-band would allow the target to be identified more easily. The ability to measure the target of interest at both frequencies simply by moving the model from one compact range to another will allow the simulation of multi-band radar systems that use lower frequencies to detect the target and higher frequencies to identify it.

4. SUMMARY

Two new compact radar ranges have been constructed to acquire X-Band and UHF ISAR imagery data using $1/35^{th}$ scale models. The new compact ranges allow data to be taken that can simulate a multi-frequency radar platform, with frequencies low enough to detect obscured targets and high enough to provide useful resolution to aid in target identification once they have been detected. Since both compact ranges use the same scale factor, this allows measurement of the same target at the two spectral regions simply by moving the target model from one compact range to the other. High resolution X-band ISAR data has been taken using the 350GHz compact range and measuring 1/35th scale-models. Agreement has been shown between X-band data sets when compared between full-scale, 1/16th scale, and 1/35th scale, with differences in correlation amplitude similar to differences observed in previous studies between targets measured using different configurations. The new VHF/UHF compact range has been described and several diagnostic measurements have been presented. Sample ISAR images taken at X-band and VHF/UHF have been shown at identical elevation angles and azimuth angles. The combination of the two new compact ranges will allow simulation of multi-band radar systems for target detection and recognition.

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